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SCALING SWAINSON'S HAWK POPULATION DENSITY FOR ASSESSING HABITAT USE ACROSS AN AGRICULTURAL LANDSCAPE

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Abstract.—By integrating population density estimates of Swainson's hawk (*Buteo swainsoni*) from other studies, I found that the areas within study boundaries consistently support much higher densities of Swainson's hawk than do the surrounding areas, and most of the variation in density was explained by the spatial extent of study. Therefore, I designed a sampling program to express habitat use across multiple potential clusters of home ranges, thereby representing the population-level interaction with the agricultural landscape of the Sacramento Valley, CA. I mapped 162 observations of Swainson's hawks in 5 yr of surveys (110 surveys) along a 204-km road transect from a car traveling at 80–88 kph. Based on use and availability of landscape elements along the transect, Swainson's hawks "preferred" riparian habitat, grassland, alfalfa stands >2 yr old during irrigation and mowing, and annual field crops during harvest. Hawks "avoided" most other crops, tilled fields, and built-up areas.

Key Words: *Agriculture*; *alfalfa*; Buteo swainsoni; *density*; *road survey*; *Sacramento Valley*; *Swainson's hawk*.

Escalamiento de la densidad poblacional de *Buteo swainsoni* para evaluar uso de hábitat a través de un paisaje agrícola

Resumen.—Por integración de densidades poblacionales de *Buteo swainsoni* estimadas en otros estudios, encontré que áreas de borde, en estudio, consistentemente soportaban mayores densidades de esta especie que las áreas vecinas y la mayoría de la variación en densidad era explicada por la extensión espacial del estudio. De manera que diseñe un programa de muestreo para expresar uso de hábitat a través de racimos potenciales multiples de rangos de hogar, representando asi, la interacción a nivel poblacional con el paisaje agrícola de Valle de Sacramento, California. Se mapearon 162 observaciones de *B. swainsoni* en cinco años de recorridos (110 recorridos) a lo largo de un transecto carretero de 204 km, realizado en un vehículo viajando a 80–88 kph. Basados en el uso y disponibilidad de elementos del paisaje a lo largo del transecto, *B. swainsoni* "prefirió" hábitat ribereños, praderas y campos de alfalfa mayores a dos años de antiguedad durante la irrigación, corte y durante la cosecha anual de los campos. *Buteo swainsoni* "evitó" otros tipos de cosechas, campos cultivados y áreas de construcción.

[Traducción de Ivan Lazo]

Knowledge of the ecological resources needed by the Swainson's hawk (*Buteo swainsoni*) is important because the species is thought to have declined radically in California (Bloom 1980), and is now listed as threatened there. This knowledge is also important because Swainson's hawk management decisions, including mitigation for development, and state and federal recovery plans, affect large investments in agriculture and construction. Swainson's hawk populations are threatened by land conversions and management decisions that leave enough ecological resources for only a minimum existence (Wilcox 1989).

Most Swainson's hawk habitat-use studies occurred within small areas immediately around nest trees or within home ranges (e.g., Gilmer and Stewart 1984, Estep 1989, Bechard et al. 1990). These intensive studies were typically constrained to small geographic areas because they were expensive and thus were required to be focused on a small number of individuals. The results of these local studies sometimes have been extrapolated to estimate habitat use in larger regions (e.g., Bloom 1980, Bednarz and Hoffman 1988), which then could be used for management decisions, without making adjustments for changes in landscape attributes nor for changes in Swainson's hawk spatial pattern.

The regional context is usually excluded from analyses during population and habitat-use studies. Such intensive studies of most species usually occur where the investigator(s) had *a priori* knowledge of high density (Schonewald and Smallwood in press).

The home range is often viewed as the spatial requirement of a species, so habitat associations are derived from observations within the home ranges. But nesting pairs choose locations for their home ranges from among many potential locations within their historic geographic range. Studies at high-density sites might not provide all the information that is needed for management of the Swainson's hawk at a regional scale. Density estimates and habitat use at small study sites could be reliably extrapolated to the region only if Swainson's hawks and habitats (and land use) are uniformly distributed across the landscape. Distribution maps of nesting pairs suggest that Swainson's hawks in California are highly aggregated (Bloom 1980, Schlorff and Bloom 1984, Estep 1989). The clusters of nest sites are where most investigations have been conducted (Schmutz et al. 1980, Gilmer and Stewart 1984, and Estep 1989).

In this paper I first test whether Swainson's hawks are uniformly distributed across studied landscapes, which would be a necessary condition for extending the results of population and habitat-use studies to larger areas. Then I complement results of intensive studies with those of a survey along an extensive road transect in the Sacramento Valley, California. The road transect was designed to sample a geographic area that was much larger than conventional population and habitat-use study areas of the valley's largest birds and mammals, and the types of agriculture that occur in the valley (Smallwood et al. in press). By exceeding the areas of conventional habitat-use studies, I was able to critically analyze the effects of agricultural crops and practices on a Swainson's hawk population.

METHODS

Scaling Population Density. From 26 population estimates in 16 research reports of Swainson's hawk studies, I recorded every estimate of nesting density within each geographic area defined for study. I used the geometric mean for multi-annual estimates made at a site. Schmutz (1984) was not used because he sampled only 4.4% of his 74 686 km² study area. Log_{10} transformed estimates of nesting density (pairs per square kilometer) were tested for linear relationships with the spatial extent of studies with the equation:

$$\text{Log}_{10}(\text{nesting density}) = a - b \times \log_{10}(\text{area}), \quad (1)$$

where a and b are the intercept and slope coefficients to be estimated with least squares regression. Model precision was assessed by examining the coefficient of determination (R^2), the root mean square error of the residuals (RMSE), and the pattern of residuals plotted against study area. The spatial pattern of Swainson's hawks across studied landscapes is increasingly homogenous (aggregated to random to uniform) as the regression slope approaches 0 in equation (1). If the hawks' spatial pattern is found to be far from homogenous, then density estimates and habitat associations cannot be reliably extrapolated to areas that are larger than the conventional study areas.

Habitat Associations. My road transect was designed to sample wildlife populations across a large geographic area in which interactions between species and the landscape could be measured. It was designed to sample interspersed landscape elements in the Sacramento Valley, including the major types of agriculture produced (field crops, rice, orchards, and pasture), along with urban and rural areas, riparian habitat, and grassland and wetland habitats in protected areas. It was also designed to provide extensive north-to-south and east-to-west coverage. The road transect was 204 km in seven segments (to provide rest periods for the investigator) along a 320-km loop around the Sutter Buttes (described further in Smallwood et al. in press).

I surveyed for wildlife from the passenger seat of a car driven at 80–88 kph at 1 wk to 1 mo intervals. Surveys always began 0700–0930 H, and typically lasted 5 hr. For multiple bird and mammal species, I recorded the species, activity, land-use/habitat association, location to the nearest 0.16 km, and side of road where the observation occurred. I mapped the crops immediately along the transect, including tilled fields, crop residues, and agricultural activities such as harvest, irrigation, and tillage. Swainson's hawk observations from 3306 km of survey (57 surveys) along the first 58 km of the transect (Davis to Sutter National Wildlife Refuge) were related to land-use and habitat elements based on the proportional occurrence of each (after Smallwood 1993, Smallwood et al. in press)

Swainson's hawk's use of alfalfa fields was further investigated during a 2-yr (1992–94) study of pocket gopher (*Thomomys bottae*) spatial dynamics in 36 Sacramento Valley alfalfa fields (Smallwood and Geng 1993b). While mapping gopher burrows by walking along borders of irrigated fields, I recorded Swainson's hawk visits from 0630–1200 H, March to September. I compared the number of visiting Swainson's hawks with my time spent in alfalfa fields of various ages and harvest phases; i.e., mowing, raking, baling hay, collecting bales.

RESULTS

Scaling Population Density. Nesting Swainson's hawks were aggregated across studied landscapes. The regression slope was significantly different from 0 ($P < 0.0001$) and substantially different from corresponding with homogeneity (Fig. 1A). The nesting density at the smallest study area was 124 times greater than the density at the largest study area when calculated from the regression, and the real difference was 310-fold. Also, the average number of pairs per 1 km² was calculated from the regression to be 2.2, which is more than can be expected at any randomly selected site across the Swainson's hawk nesting range. Therefore, the Swainson's hawk studies used in the regression analysis were consistently conducted at sites where Swainson's hawk population densities were much higher than across the surrounding, unstudied areas.

All of the density estimates were made after intensive ground searches for nests, although Platt (1971) included aerial searches and Littlefield et al. (1984) searched from the road. The searches were reported to be complete or inclusive of all nests in 56% of the studies and 70% of the density estimates. However, whether or not the search was reported to be complete did not influence the residual variation that remained after density was regressed against study area (Independent samples $T = 0.59$, df $= 19$, $P = 0.56$). Instead, this residual variation appeared to cycle with a periodicity of about 10 yr (Fig. 1B). This possible, range-wide population cycle could not have been recognized from the existing data without removing the variation in density due to the spatial extent of study area.

Habitat Associations. I made 162 Swainson's hawk observations during the entire road survey, but only 130 were used in the habitat-use analysis from the cumulative 3306 km along the first 58 km of transect during March to October. My observations were nearly evenly distributed among months from March ($N = 24$) until October ($N = 13$). Most (82%) were of birds in flight, 11 (7%) were on trees, five (3%) were on the ground, and 7% were on artificial structures such as utility poles and fence posts. Swainson's hawks occurred more often than expected by chance in alfalfa, riparian, and grassland habitats, where they occurred throughout the breeding season (Fig. 2A). The remainder of the landscape elements were used by Swainson's hawks preferentially only during brief periods of opportunity; e.g., in tomato fields 21.7 times more often during harvest than expected by chance. The 16 Swainson's hawks I saw at tilled fields were during early spring and fall when most of the landscape was tilled or being tilled (Fig. 2B). Rice stubble left through the winter was used by Swainson's hawks during early spring, but overall rice stubble was avoided by Swainson's hawks. Safflower and some other crops were never used, not even after harvest (Fig. 2A).

Both the road survey and gopher sampling revealed that Swainson's hawks used alfalfa most often while those fields were being irrigated, and secondly during hay harvesting (Figs. 3 and 4). These preferences were greatest in alfalfa that was 3–4 yr old

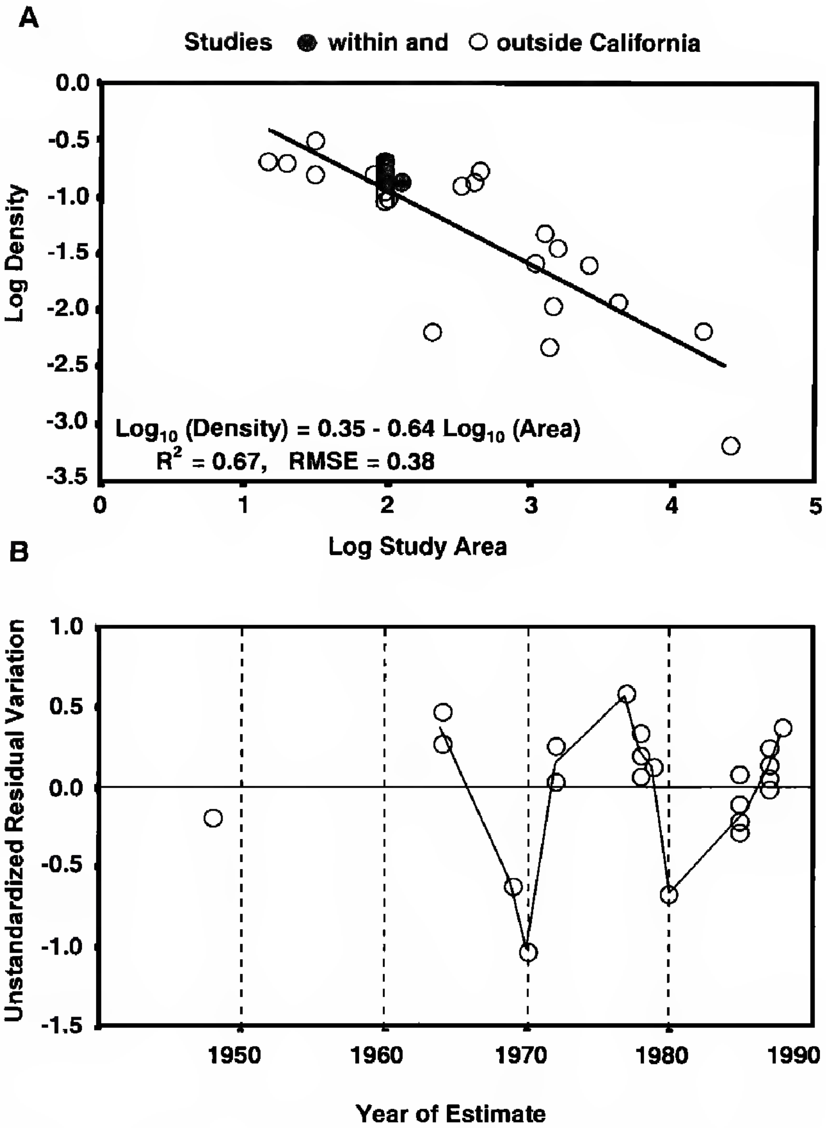

Figure 1. Log-transformed estimates of Swainson's hawk population density decrease linearly with increasing log spatial extent of study area (A), and the residuals suggest an approximately 10-yr population cycle (B) fit by lowess smoothing on 20% of the data. Estimates were from Craighead and Craighead (1956), Platt (1971), Smith and Murphy (1973), Olendorff (1975), Dunkle (1977), Fitzner (1978), Bloom (1980), Schmutz et al. (1980), Bechard (1983), Littlefield et al. (1984), Bednarz and Hoffman (1988), Gilmer and Stewart (1984), Estep (1989), Restani (1991), and Bosakowski and Ramsey (unpubl. data).

(Figs. 3 and 4B). All of the 31 Swainson's hawks seen in alfalfa fields during the road survey were at fields being irrigated, which comprised 0.02% of the transect. Thus, Swainson's hawks were 858 times more likely to occur at mowed and irrigated alfalfa fields than if they occurred randomly along the transect.

DISCUSSION

Scaling Population Density. Most of the variation in Swainson's hawk density was explained by

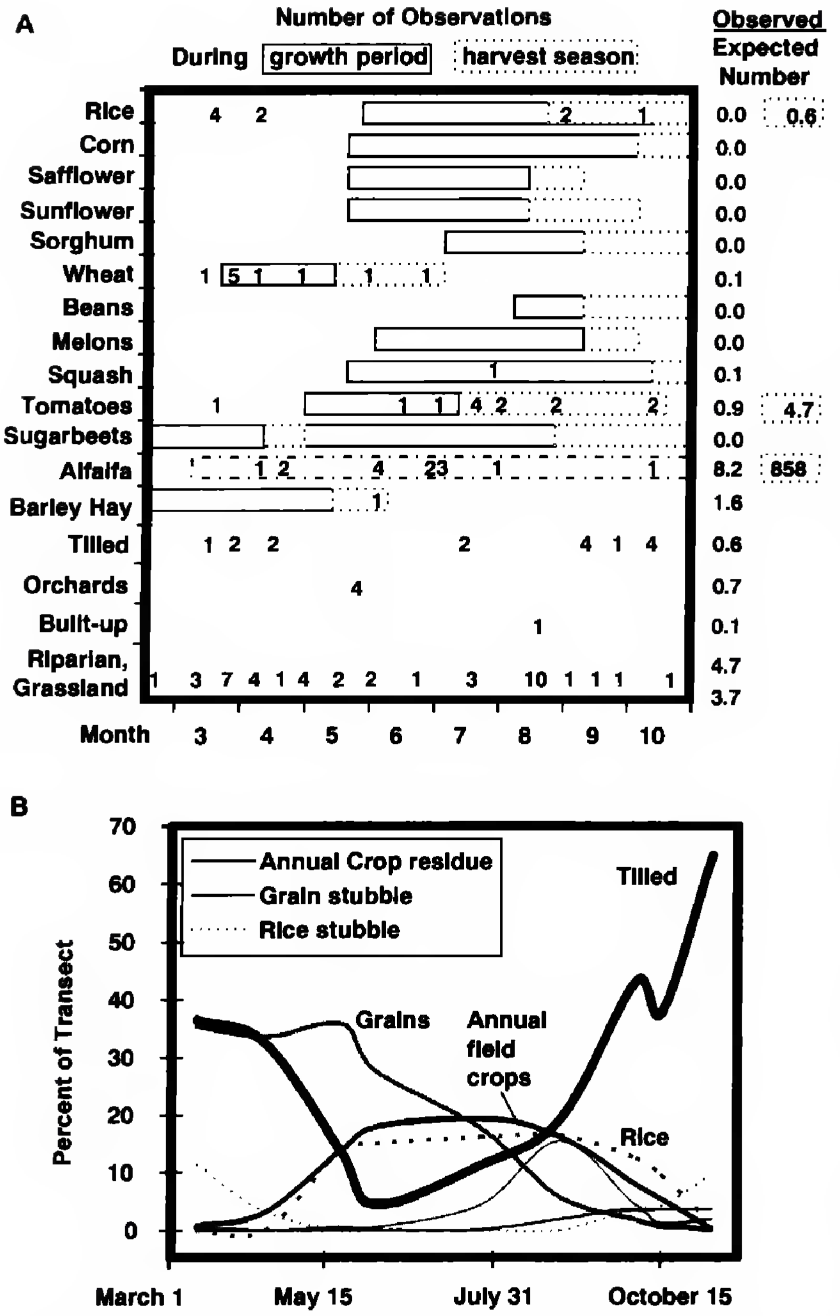

Figure 2. The Swainson's hawk distribution among habitats during the nesting seasons of 1990–94 (A) and the 1993–94 moving average of agricultural field conditions expressed as a percent of the southern 58 km of the road transect (B). Expected values are the total number of hawks observed multiplied by the proportion of each habitat in the sample.

the spatial extent of study, consistent with results for other species (Schonewald and Smallwood in press). This means that most study methods have little influence on density estimates, if the methods are rigorous. Except for Schmutz (1984), the residual variation in density estimates based on different methods plotted precisely along the lowess curve that suggests a population cycle (Fig. 1B). Clearly, results from conventional studies cannot be extrapolated to larger geographic areas without at least making analytical adjustments for the change in spatial scale.

Judging from the scientific literature, investigators were previously unaware of the magnitude to which density changes with the spatial extent of study. Bloom (1980) multiplied his density estimate in the Klamath Basin by 0.25 (25% of the then known maximum density in California) to estimate the population size across the Swainson's hawk's historical range in California, which was estimated from topographic maps, field surveys, and the literature. Bloom's minimum estimate was 4284 pairs and his maximum estimate was 17 136 pairs. Using the model in Fig. 1, I calculated a mean population 404 pairs (SD = 166) across this historic range, which falls between the estimates of 375 and 550 pairs for 1979 (Bloom 1980) and in 1988 (California Department of Fish and Game 1990), respectively, and which is much less than Bloom's historic estimates. But my calculation should not be expected to be a reliable estimate of the historic Swainson's hawk population. The regression model in Fig. 1 can provide precise estimates within the data range (high to low values of densities and study areas), but is less reliable for an estimate across the historic distribution, because we do not know whether the log-log relationship between density and area remains infinitely linear. The habitat conditions have been altered radically, so there could have been more Swainson's hawks based on habitat availability. Nevertheless, the population might not have been much larger because it was naturally aggregated despite habitat availability, and the regression model showed that study areas such as Bloom's (1980) typically have much higher densities than areas not studied.

Study areas may be fundamentally different from the surrounding areas. The average square kilometer of land does not support 2.2 pairs of Swainson's hawks as predicted by the regression model in Fig. 1. Study areas are probably dissimilar to unstudied areas in terms of habitat conditions, but habitat-use studies only occur within the boundaries of study areas. Little connection has been made between habitat conditions on study areas and those beyond the study boundaries. Therefore, different habitats on study areas are used significantly more and less than if the study boundary encompassed a much larger geographic area. My road survey was designed to complement conventional habitat-use studies by linking habitats in areas of Swainson's hawk aggregations with habitats in the surrounding landscape. Other road surveys have been conducted for Swainson's hawk habitat use, but the transects were arranged for a more intensive survey within the area of aggregations.

Habitat Associations. My survey design resulted in conclusions about habitat use by Swainson's hawks which differed from other reported studies. Swainson's hawk use of riparian habitat, grassland, and alfalfa were greater in my study, probably because the greater spatial extent of study provided a much lower estimate of the availability of these habitat types. In my study Swainson's hawks seemed to avoid irrigated pasture, tilled fields, annual field crops, and developed areas, probably because the availability of these habitat types was much greater across the larger landscape.

My results also show that the majority of the agricultural landscape is inhospitable to nesting Swainson's hawks most of the time (Fig. 3). Prey availability is usually greater during crop harvest when prey are exposed by the removal of the canopy that persisted during the growth period. Swainson's hawks opportunistically forage over field crops during or just following harvest or irrigation. But these opportunities occur briefly at each field. The brief foraging opportunities in alfalfa occur mostly in fields at least 2.5 yr old, after prey populations have increased to sufficient levels (Smallwood and Geng 1993a,b).

Conservation Implications. The most effective opportunities for Swainson's hawk conservation might be in the management of agricultural landscapes where nesting and foraging habitat limit population size. Swainson's hawk nesting density increased in cultivated areas where tree density (Schmutz 1984) and prey availability (Bechard 1982) were highest. Swainson's hawk conservation would benefit substantially from the protection and restoration of riparian forests with large cottonwoods and oaks, and by managing field borders, road verges, and canal banks as strip corridors of grasses and shrubs. The lack of movement corridors for small mammals in the Sacramento Valley probably decreased populations of small mammals (Smallwood 1994) which are prey of Swainson's hawks. Pocket gophers, one of the important prey species (Bechard 1982, 1983, Gilmer and Stewart 1984, Restani 1991), are controlled in many alfalfa fields because they are thought to reduce alfalfa yields. Vertebrate pest management could be altered to the benefit of Swainson's hawk by better understanding the relationship between "pests" and agricultural crops. Van Vuren and Smallwood (in press) described many alternative vertebrate pest management strategies, most of which are not currently used. Even orchards and vineyards, which are generally considered to be poor Swainson's hawk foraging areas, can provide habitat for prey when cover crops are grown. Cover crops serve as habitat and alternative food (rather than the commercial crop) for small mammals, which will disperse into habitats that are more accessible to foraging Swainson's hawks. Thus, agriculture might actually benefit Swainson's hawks so long as the critical resources are maintained and/or enhanced.

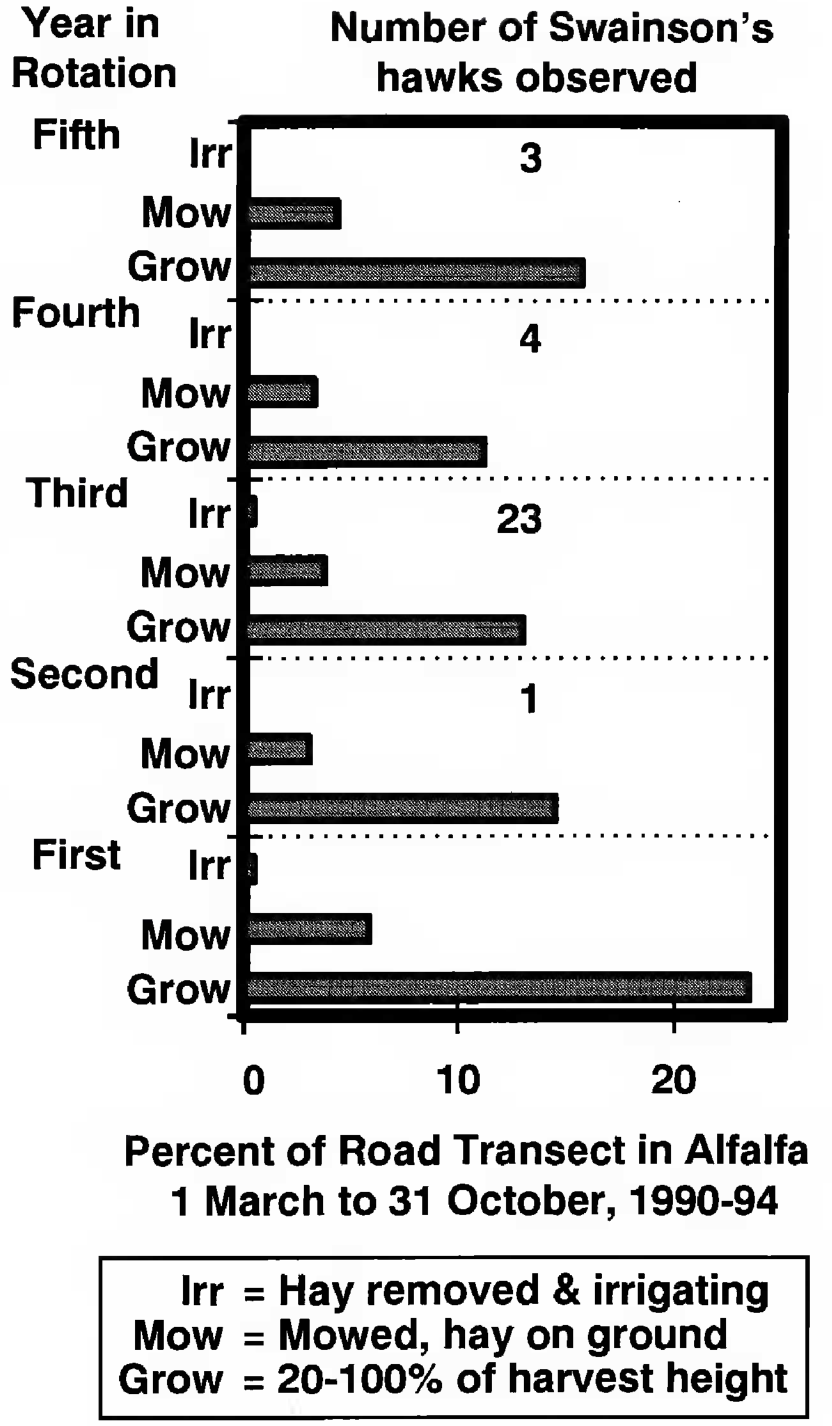

Figure 3. Swainson's hawk occurrences at alfalfa fields along the road transect.

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